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SOME PROBLEMS IN ECOLOGICAL PHYSIOLOGY

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ABSTRACT

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The author enumerates some problems of space physiology still to be solved. Comprehensive study of the effect of environmental factors and their actions has led to the formulation of ideas on physiological methods of increasing the resistance of man, and to the recommendation of techniques for protection of man against injurious environmental factors.

Author

The rapid tempo of development and continuous expansion of research in the field of space physiology has naturally given rise to the need for reviewing the results to date and for analyzing the outlook for this branch of knowledge.

Although only a little more than seven years have elapsed since the first biological satellite was launched, our knowledge has increased greatly. We not only have extensive data obtained in experiments on animals, but unevaluated information from the flights of the cosmonauts.

It is not the purpose of this paper to survey the available materials, since in the limited time at my disposal I could scarcely cover the work done, even that in my own country. Rather, I shall confine myself to a discussion of the general trends of research in ecological physiology, citing experimental data obtained mostly in 1964 simply to illustrate some of my points.

In rapidly developing fields of knowledge, especially those at the junction of several scientific disciplines, it is often difficult to determine the boundaries of their interests and competence. This ~~is~~ far from being an idle matter, and I should like to comment on it briefly.

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Ecophysiology (space physiology) can now be regarded as a group of biological disciplines concerned with the vital activity and behavior of living organisms when exposed to space conditions or to space flight on rocket-propelled vehicles. The variety and complexity of the problems involved cannot be solved without extensive use of the ideas and methods not only of physiology,

*Numbers in the margin indicate the pagination in the original foreign text.

but of biochemistry, biophysics and other branches of biology. As a result, the boundary lines delimiting the competence of space physiology are fairly provisional and temporary. The interests of this branch of knowledge are often intertwined with those of exobiology, general and applied ecology, radiobiology and some others. However, regardless of the specific research methods used by space physiology, regardless of how deeply it has penetrated into the allied sciences, its main objective is to provide the physiological basis of the ways and means of preserving the normal activity of living organisms under extreme conditions.

Comprehensive study of the effect of environmental factors and their varied mechanisms of action has led to the formulation of ideas on physiological methods of increasing resistance and to the recommendation of techniques for providing protection against injurious environmental factors. It also determined the ecological constants of an artificial habitat.

The effect of environmental factors on living organisms continues to be a major object of study for these reasons. The possibility that the activity of living systems can be preserved is bringing closer the solution of the biological problem of life existing in space, where external conditions are arduous for terrestrial forms of life. Here the interests of space physiology are intimately connected with those of exobiology. Moreover, a knowledge of the reactivity of living organisms to extreme environmental factors and data on the limits of resistance to or tolerance of these factors is of value in devising and perfecting biotechnical systems and in developing methods of increasing resistance. /3

The environmental conditions under study include both factors characteristic of space and those caused by the nature of the spacecraft. The first comprise vacuum, cosmic and solar radiations, temperature, etc. The latter include pressure, gaseous composition of the atmosphere, temperature in the vehicles, etc., as well as such dynamic factors as acceleration, vibration and weightlessness. Not only is the effect of each being studied separately, but various combinations of these factors are receiving increasing attention by investigators, despite the technical difficulties connected with the experiments. However, the tolerance of specific extreme factors, including those characteristic of the space environment, remains an urgent subject for investigation, as shown by the flight of "Voskhod-2." /4

Considerable attention has been focused of late on the reactions of organisms and individual cells to low and superlow temperatures. Investigations in the laboratory of L. K. Lozina-Lozinskiy revealed that there are representatives of the systematic groups of animals, excluding the vertebrates, which can tolerate extremely low temperatures (close to absolute zero), owing to their biological and ecological characteristics. Moreover, almost all cells, even those of vertebrates, are potentially resistant to chilling below -80° or, in the presence of protective substances, to -269° . Under the conditions of complete anabiosis at the temperature of liquid gases, it appears that life can be maintained indefinitely without reducing the activity of the integral organism or its cells. The results of these experiments with unicellular organisms and insects have important implications for space biology. Low /5

temperatures as well as deep freezing do not seem to jeopardize the survival of bacteria, yeasts, invertebrates and, possibly, even some warm blooded vertebrates.

Efforts should be intensified to determine the limits of safe, reversible chilling of living systems, particularly at the cellular and molecular levels. New and interesting data can be expected from such research. Study of cryolysis, radiolysis, photolysis and their combined action on nucleoprotein molecules will undoubtedly help to elucidate the effect of several physical agents on the resistance or death of living systems. For example, M. A. Khenokh noted a number of qualitative changes in proteins and desoxynucleoproteins after deep freezing and after the combined action of chilling and radiation (gamma rays of Co^{60} and ultraviolet irradiation). Freezing (-78°) of solutions of desoxynucleoproteins was found to produce a precipitate, with an increase in the characteristic viscosity, loss of molecular weight, and increase in asymmetry of the molecules noted in the liquid phase. The effect of gamma rays, varying with the dose, alters the molecular weight and degree of aggregation of the molecules. Large doses cause the molecules to aggregate along their long axis and form fairly well branched molecules. These phenomena occur less intensively in frozen solutions. /6

Ultraviolet irradiation induces changes similar to those resulting from radiolysis. Gamma rays at both positive and subzero temperatures break the bond between protein and DNA. The dialyzates have products containing nitrogen and phosphorus.

According to A. A. Imshenetskiy et al., certain enzymes are altered by low temperatures. Polarography reveals that protein is subjected to molecular rearrangement in which the hydrogen links take part. The energy of activation decreases most steeply when the temperature is lowered to -3° , because the reduction of such energy is related to the intramolecular rearrangement of the enzyme (trypsin).

Of great interest are the investigations on chilling of higher animals, particularly in view of the potentialities of artificial hypothermia and anabiosis. Artificially chilled organisms are known to be highly resistant to oxygen starvation and some other injurious agents. This justifies some optimism on the possibility of using such a biological defense for emergency situations on space flights (N. N. Sirotin, G. D. Glod et al.). /7

We have some evidence that animals in a state of artificial hypothermia can withstand fairly intense and prolonged acceleration, ionizing radiation, and other factors (V. I. Danilevko, G. D. Glod, V. S. Oganov, N. N. Timofeyev, and others). White laboratory rats in a state of reversible deep freezing (body temperature $+3^{\circ}\text{C}$) can tolerate actions of such intensity (acceleration, hypoxia) as to be absolutely incompatible with life in the case of intact animals (G. D. Glod).

Unfortunately, we still do not have methods for safely reducing reactivity over a long period of time. Research in this field should be vigorously

carried out. When man emerges into free space, we have to expect that under certain conditions he will also encounter the effects of hypothermia. This problem also has to be evaluated by physiologists, with due regard for the specific conditions of heat exchange in weightlessness.

In determining the limits of tolerance of high temperatures, ecophysiology may utilize the extensive information gained in other branches of physiology and occupational medicine.

The second extreme factor in space is high vacuum. The recent /8
studies of A. A. Imshenetskiy and his co-workers have demonstrated that several micro-organisms are very resistant to this factor. For example, *Aspergillus terreus*, *Micrococcus aurant*, and some algae like *Chlorella vulgaris*

readily tolerate a vacuum of 10^{-8} to 10^{-9} mm Hg. This information is significant for exobiology, specifically in connection with the problem of trans-spermia. However, it is a well-known fact that for the more organized living objects even lesser intensities are fatal.

The various kinds of radiation have unusual biological activity.

It was once thought that ultraviolet rays in space were lethal to living organisms. However, it has been found that certain factors may nullify this effect. For example, photoreactivation and the screening effect of various chemical substances that are part of the cells and their membranes (e.g., pigments) are capable of increasing the general resistance of the cytoplasm and nucleus to ultraviolet. It is quite likely that the injurious effect of ultraviolet radiation on terrestrial organisms is due primarily to the fact that they failed to adapt to it, or perhaps lost their resistance to it in the course of evolution. It is interesting to note that the enzyme of photoreactivation may be used only when the cells are exposed to rays that do not reach the Earth's surface. However, ionizing radiation reduces the effect of photoreactivation.

Cytological investigations of the effects of shortwave ultraviolet radiation have additional practical value for space physiology. The /9
physiological, cytochemical and morphological changes observed in some infusorians may serve as delicate indicators of the biological effect of ultraviolet radiation, i.e., as dosimeters.

"Ultraviolet starvation" and determination of the permissible level of irradiation of a spacecraft crew are other matters of practical interest to physiologists concerned with long-distance flights. The outfits planned for the use of cosmonauts when outside the vehicle will naturally furnish protection against the injurious effect of ultraviolet radiation. There are numerous problems involved in choosing suitable materials for such outfits.

A much graver danger is ionizing radiation. This is a special problem falling within the competence of radiobiology and will not be discussed here, although in some important aspects it is closely related to problems in space physiology. This is especially true for study of the combined effects of

several factors, including irradiation. The more or less complete artificial reproduction in the laboratory of the conditions of outer space and various planets is a good model for such investigations. I should like to discuss briefly some of the work that has been done in simulating the climate of Mars.

An experimental chamber was designed to duplicate the gaseous composition of the atmosphere, pressure, temperature and ultraviolet rays prevailing on this planet. It was found that only the last factor inhibited the activity of micro-organisms. Spore-forming bacteria and pigment micro-organisms were the most resistant. Fungi forming a black pigment withstood an ultraviolet dose of $4.04 \cdot 10^8$ erg/cm², further evidence of the protective role of pigment (A. I. Zhukov et al.). /10

These investigations also showed that not only thin layers of soil, but even microbial cells provide good protection against ultraviolet rays. For example, a screen consisting of a single layer of cells (1.9μ in diameter) reduced the bactericidal effect of the rays fourfold.

Furthermore, Lozina-Lozinskiy's laboratory also studied the developmental cycle of soil infusorians under Mars-like conditions. They were found to be capable of adapting to the daily change in temperature on Mars, to periodic drying out and freezing to -78°. These unicellular animals seem to be the kind that could live in Martian soil or in the vegetative covering of this planet. Their resistance is apparently due to hardness resulting from the ability to tolerate the loss of water.

These examples illustrate the striking range of adaptation capabilities possessed by various representatives of organic life on Earth. /11

The discovery of the intimate mechanisms of adaptation of living organisms to extreme space conditions has paved the way for methods of increasing their resistance and revealed the principles on which protective measures can be based.

Let us now turn to the role of the dynamic factors, which may be even more significant at this stage in the history of space science than those examined previously.

There is a vast literature with outstanding works by many authors on physiological analysis and determination of the limits of human tolerance.

Owing to practical needs, preference was given to lateral acceleration, the transitional state between acceleration and weightlessness and weightlessness. This branch of space biology is growing rapidly and successfully. It is impossible to mention even the major achievements. It is more worthwhile, perhaps, to comment on some of the obscure aspects that have received comparatively little attention.

The investigations undertaken by Ya. A. Vinnikov, V. G. Yelisseyev et al. with the help of the electron microscope and histochemical methods enabled them

to reexamine the changes in structure and function of cells of different tissues and organs in response to acceleration.

It is still too early to evaluate the results, but we have the impression that the pathogenetic mechanism of cell injury is fairly complex. /12 Such injury is apparently not always reflected in the dynamics of the external indices of physiological functions, but ultimately there is distinct impairment of the enzymatic systems, metabolic changes and even damage to cell structure.

It seems to me that while the general mechanisms responsible for regulating functions are properly a matter of concern, more attention should be paid to the processes that take place at the cellular and subcellular levels. It is pertinent to recall the studies of N. P. Dubinin, M. A. Arsen'yeva et al. on the nuclei of mouse bone marrow and spleen cells. These investigators found that space flight gives rise to specific, unusual nuclear anomalies in the form of chromosome adhesion and some increase in the number of aberrations. Later investigations carried out on the ground showed that vibration (35-70 cps, 60 min) affects mitosis and causes the type of impairment observed after space flight. Centrifugation of mice (8-20 g) revealed that this factor also affects the nucleus.

Similar phenomena were noted in experiments involving the free flight of an airplane along Kepler's parabola with the combined action of vibration, acceleration and weightlessness. The inclusion of a factor like weightlessness significantly increased the frequency of fragmentation and, presumably, nonbreakage of chromosomes. /13

Thus, study of the effect of dynamic space factors individually and combined with radiation showed that they impair the process of cell division. It is reasonable to assume that the changes in normal cell division in the circumstances described are brought about either indirectly through hormonal and immune alterations or directly through influences on the cell apparatus (adhesion of chromosomes during different stages of the cell cycle, displacement and ejection of chromosomes from the spindle). The basis of these phenomena is obviously interference with the process that prepares the way for cell division and dysfunction of the apparatus of division. Prolonged exposure to factors that disrupt cell metabolism may extend the cell cycle, suppress DNA synthesis and cause chromosomal aberrations. Analysis of the various phases of the cell cycle in mouse bone marrow following exposure of the animals to vibration and centrifugation revealed that the presynthesis and synthesis stages of DNA are most sensitive to these factors.

Study of agents that may counter the effects of vibration showed that some of them, e.g., serotonin, protect bone marrow cells against such impairment as adhesion of chromosomes. /14

These, then, are some of the facts, insufficiently investigated, that characterize the changes arising at the cellular and subcellular levels in response to dynamic flight factors.

It is still difficult to evaluate these changes fully, as far as the functional state of the organism is concerned. As I mentioned previously, no appreciable changes have been observed in physiological functions, in the main clinical constants of peripheral blood, in behavior or efficiency. Consequently, there are no grounds for exaggerating the significance of these facts, let alone for regarding them as dangerous. Yet, I repeat, they must be carefully considered, especially in connection with extended flights. Moreover, they help to fill out the picture of the general changes, a picture in which there are still quite a few "blank spots."

For example, the reaction of the nervous system to acceleration is still somewhat obscure. We have a right to expect important data from delicate electrophysiological investigations which include the hemodynamic changes that may result from acceleration.

As is evident from the interesting studies of Yu. Ye. Moskalenko et al., the rapid rate of cerebral blood flow and the nature of the anatomical structure of the intracranial vascular system suggests that one of the reasons for the disorders developing in humans and animals after exposure to gravitational loads is impairment of the cerebral blood supply. Pertinent experimental data indicate that the intracranial circulatory system is highly sensitive to the redistribution of blood caused by gravitational forces, and that the body has considerable compensatory capabilities for ensuring satisfactory blood supply to the central nervous system within a wide range of gravitational loads. Moreover, the limits may be extended by planned training and, possibly, by the use of some pharmacologic agents. /15

Once again we see that as our knowledge of the mechanisms of action of individual factors increases, we find ourselves in a position where we can influence the course of events more or less as we wish. In this connection, I should like to refer to the experiments of P. V. Vasil'yev et al., which showed that the sensitivity of animals to certain pharmacologic agents (glucoside, sympathomimetic drugs, narcotics) markedly changes in the period following exposure to acceleration.

All this information will help us to make more efficient use of drugs, as well as to gain deeper insights into the pathogenesis of the disorders occasioned by acceleration.

From the very beginning of space physiology, weightlessness has been an extraordinary problem. The difficulty in simulating this state on the ground made the experiments on spacecraft the principal method of studying the phenomenon. The successful flights of the cosmonauts, especially the 5-day trip of V. Bykovskiy, and the brilliant feat of A. Leonov in stepping out of his craft rightly generated feelings of satisfaction and optimism. Yet, a comprehensive and sober appraisal of the level of current knowledge reveals that the problem still requires the most earnest attention. /16

Besides the functioning of the analyzer system, hemodynamics and metabolism, research should be conducted in two directions: (1) tolerance of acceleration after preliminary exposure to weightlessness, and (2) physiological effects of prolonged weightlessness.

P. A. Kurzhuyev's observations are of interest. After investigating changes in hemoglobin synthesis in the course of animal phylogenesis and the situation that arises as animals emerge onto dry land from water, the author concluded that the evolution of this function is an experiment by nature lasting millions of years, an experiment that may provide indirect information for solving one of the aspects of weightlessness.

The author's premise is that living in water, unlike that on land, is similar in some ways to living under weightless conditions. Relying on the fact that bone marrow appears in terrestrial vertebrates and progressively /17 develops in the higher land mammals, while it diminishes in aquatic mammals adapted to the medium, the author advances the hypothesis that prolonged weightlessness may have an extremely adverse effect on hematopoiesis.

I should also like to recall an idea of K. E. Tsiolkovskiy (1882), still valid, on the possibility of significant changes occurring in organisms exposed to weightlessness. It seems to me that we must reckon with the probability that those remaining a long time in space stations or traveling on an interplanetary spacecraft will have to have artificial gravity, the optimal parameters of which should be determined as soon as possible.

Other prophylactic measures will have to be devised to combat the undesirable effects of prolonged weightlessness, e.g., careful selection and training of cosmonauts, devising preventive rest and work routines on the spacecraft, etc.

The recent experiment on "Voskhod-2" also demonstrated the exceptional importance of detailed study of the biomechanical aspects of the long-range problems relating to the assembling of space objects and the cosmonaut's performing a variety of tasks outside the vehicle.

The progress made in space physiology will help to provide practical solutions of the life-support problems involved in extended space flights. /18 Of greatest value are the physiological investigations designed to find ways of creating an artificial atmosphere in the cabins of spacecraft. It is essential to determine, for example, the limits of permissible variations in such parameters as barometric pressure, composition of gases, humidity and temperature. Much was learned about them as experience was gained in designing the vehicles.

Considerable attention has been focused of late on the composition of gases for the pressurized cabin. Solutions have been found and tested for short flights, but not for extended flights. The many attempts to use helium are highly interesting. A. G. Zhironkina et al., for example, established experimentally the maximum permissible safe concentrations of oxygen mixed with helium for various representatives of the animal world. They also obtained some encouraging experimental data on prolonged exposure to helium. Specifically, they found that in a prolonged experiment both animals and human beings prefer to breathe helium-oxygen rather than nitrogen-oxygen mixtures, due to the physical properties of helium which help to reduce resistance to respiration and increase alveolar ventilation.

V. V. Boriskin et al. studied the effects of prolonged exposure to a helium-oxygen mixture on the development of biological objects with different levels of organization. No differences were noted in frog eggs and chick embryos either in the time or nature of the embryogenesis of embryos, whether they were incubated in a helium-oxygen or nitrogen-oxygen mixture. /19

The investigations of A. G. Dianov, A. G. Kuznetsov et al. have practical implications in that they demonstrate the possibility of human beings staying a long time (10-25 days) in a helium-oxygen atmosphere. No changes were noted in the main physiological functions, except speech. For example, according to Yu. V. Krylov, breathing a helium-oxygen mixture forces the audible speech spectrum to shift toward the high frequencies by about 0.7 of an octave. The reduction of intelligibility does not fall below an acceptable level. Research should be continued in this field, especially to determine the biological significance of other inert gases, as L. A. Orbeli suggested.

Since designers have a natural tendency to build cabins containing low pressure, studies are under way on the possibility of organisms surviving a prolonged stay under such conditions.

D. I. Ivanov, V. B. Malkin et al., for example, demonstrated experimentally that human beings can remain exposed as long as 30 days to low barometric pressures, corresponding to altitudes of 3000, 5000, and 7000 meters, provided that normal partial pressure of oxygen is maintained by enriching the atmosphere of the cabin with it. The authors failed to detect any significant impairment of function attributable either to low barometric pressure or to high oxygen content. /20

The results of these and other studies are quite promising. However, it seems to me that much difficult work remains to be done. High degrees of rarefaction harbor the danger of potential decompression disorders, while an increase in oxygen concentration may be toxic. These difficulties can surely be surmounted by creating an atmosphere in the cabin suited to flight conditions, but it will not be easy to provide for emergency situations.

Fairly complex and specialized problems face ecophysiologicalists in connection with the design of artificial ecological systems, in which the use of various species of animals and plants have been suggested as individual links.

The characteristics of growth of the biomass, production of oxygen, uptake of carbon dioxide, resistance to unfavorable factors--the solution of these and many other problems by physiologists is awaited by specialists in the field of ecosystems.

Moreover, as A. B. Rubin et al. showed, description of the behavior of a living ecological system requires many new approaches in order to determine its stability and reliability. This is possible only if modern mathematical and thermodynamic methods of analysis are used. /21

Space physiology is also concerned with the physiological rhythms associated with prolonged flights, establishment of scientifically sound work and rest routines and many other matters deserving independent consideration.

On long flights the cosmonauts may be exposed to a variety of unfavorable factors. This makes it essential to achieve the maximum possible increase in adaptation reserves, while training personnel for such flights. There are theoretically two but not mutually exclusive ways of doing this. One is to use various training routines, which naturally increase the adaptation reserves of the body. The other is to use pharmacologic and biologically active agents.

Since space flight involves simultaneous exposure to many factors, the idea naturally arose of using training methods with a broad spectrum of non-specific action. The means of increasing adaptation reserves should, of course, also include those which strengthen the specific defense mechanisms against the most important flight factors.

The following example is illustrative. Resistance to lateral acceleration may be strengthened by nonspecific training methods such as physical exercises and active acclimatization in mountains. At the same time the acceleration-induced disturbance of voluntary movements, respiration and speech can be overcome by training on a centrifuge, by developing suitable motor habits in the subjects and teaching them how to breathe and speak under these conditions. /22

The search for an efficient system of training cosmonauts inevitably led investigators to consider mountains. It was reasonable to assume that acclimatization to high-altitude conditions, especially when combined with muscular exertion, would be an effective procedure. The studies made in recent years in the Caucasus and Tien Shan showed that after fairly long "graduated adaptation" to altitudes of 2000 and 4000 meters with occasional climbs to greater heights, individuals become much more resistant to acceleration (1.5-2 g) and acute hypoxia.

Adaptation is an exceptionally complex process, one that embraces literally all levels of regulation and almost all the physiological systems of the body.

This is probably the reason that our knowledge is far from complete and that a considerable number of scientists are still working on the problem. /23

The experiments of N. N. Sirotinin, Z. I. Barbashova, V. B. Malkin, et al. showed, for example, that animals (white rats), in which the cerebral cortex, hypophysis, adrenals and thyroid had been separately removed, adapted to hypoxia. However, the underlying mechanisms often developed in a peculiar fashion. For example, after prolonged exposure to high-altitude conditions, hypophysectomized animals did not exhibit the characteristic reaction of erythropoiesis, yet their resistance to acute hypoxia tended to increase.

Research on adaptation processes at the cellular and subcellular levels seems to me to be extremely promising. We are entitled to expect significant progress in this field, especially when modern methods of studying tissue respiration are used.

Thus, the available evidence suggests that directed change in resistance is possible for any organism from man to plant cell. The means of doing this are

the same in principle for almost all animals. It is the repeated action of agents addressed, ultimately, to cellular metabolism, which induce adaptive changes in cell chemism. These agents include hypoxia, muscular work, change in environmental temperature and some drugs. The single action of some factor may by itself increase resistance. For example, a single exposure to /24 acute hypoxia or performance of strenuous muscular work brings about changes in cell metabolism. These are accompanied, in the case of physical exertion, by intensified expenditure of energy and adaptive increase in activity of the oxidation-reduction enzymes, intensified anaerobic release of energy and resultant accumulation of incompletely oxidized metabolic products, and by an increase in the oxygen debt. The restorative period is marked by excessive accumulation of sources of energy (glycogen, phosphocreatine), proteins-enzymes and a variety of biologically active substances (myoglobin, glutathione, ascorbic acid, creatine, etc.).

These processes occur in various tissues. The trace reactions gradually disappear, unless the same stressors are applied again. Repetition renews the changes in the biochemical processes of the cell, followed by the onset of a restorative phase. The most important thing is that the adaptive processes are completed. They become more efficient, the effects cumulative and reinforced, i.e., they persist for a considerable period of time. The result is what we call adaptation. The cells learn, so to speak, to react more economically and "appropriately" to the stressors as the resistance of the cell structures increases.

It will be noted that changes in cell chemism are not limited to /25 changes in the nature and intensity of the metabolic processes. There are obviously some other processes with a still obscure mechanism that strengthen the resistance of the cell structures to a great variety of agents, which are addressed to the metabolic processes and at the same time directly influence the native structure of the cell. For example, it was found that rat muscle and cerebrocortical tissues become more resistant to ethyl alcohol or high concentrations of caffeine after they become adapted to hypoxia. The sorption properties of reticuloendothelial tissue with respect to vital stains decrease, while the osmotic resistance of the erythrocytes increases. The structural rearrangements of muscle tissue can also be judged from changes in the electric conductivity and dielectric permeability of muscles in vivo. The properties of the structural and contractile proteins of skeletal muscle change in a definite way. It was found that in rats, adapted to hypoxia, the rate of restoration of the actomyosin complex following its dissociation by ATP is higher than in control animals (Z. I. Barbashova).

Since the effects of entirely different stressors on cell chemism have several features in common, it is easy to understand why training for hypoxia, for example, increases resistance to acceleration, radiation, chilling or performance of strenuous muscular work.

Experimental data show that changes in cell chemism in response to /26 extreme factors occur at all levels of organization. Adaptation to repeated exposure to these stressors is accompanied by an increase in nonspecific resistance. Consequently, we are quite justified in thinking that adaptive changes at the cell level are the basis of nonspecific resistance.

The need for continued research to find nonspecific methods of increasing resistance to extreme factors, combined, of course, with specific training methods, is evident. The latter should include those aimed at improving the neurohumoral mechanisms responsible for regulating physiological functions and for forming and reinforcing the skills needed by the cosmonauts to carry out their routine tasks, research and other activities.

Exceptionally valuable materials for such investigations are provided by the observations made during actual space flights. Each flight represented a new and important step forward in gaining mastery over space. Each directed our attention to new aspects of space physiology. The 5-day flight of V. Bykovskiy on "Vostok-5" and the flight of P. Belyayev and A. Leonov on "Voskhod-2" with the first emergence of man into space yielded unusually significant physiological data.

Despite the operations involved in using the air lock, the prescribed /27 regime was maintained on "Voskhod-2" throughout the flight: air temperature about +18°C, humidity 35-40 percent, pressure equal to the normal Earth pressure.

The crew landed the craft using the manual control system. In this, as in the preceding flights, there were no health problems, nor did the postflight examination reveal any abnormalities.

The most interesting aspect, of course, was the cosmonaut's efficiency and biomechanics of his free movements after he stepped out of the cabin. Here are some of the impressions of Leonov in his own words:

"It was impossible to stop the rotation by any movements whatever, which I knew from my preflight training, and now I expected only to slow the rotation by twirling the rope. And, actually, the angular velocity gradually decreased. In truth, by grabbing the rope I could have halted the movement of my body around the transverse axis, but I didn't want to do it. That way there were more opportunities to look around and it was unnecessary to waste time.

"After a while I vigorously braced myself, seized the rope, and had to use my hands to protect myself from the spacecraft that had begun to rush toward me. I first had to think about preventing the illuminator in my /28 helmet from striking the craft. But flying up to the air lock, I used my arms to absorb the blow. This was very easy to do, and I became convinced that once I became used to it, I could move about efficiently and in a coordinated fashion under these unusual conditions. I felt excellent and in a cheerful mood and reluctant to leave the free space. Even after I was ordered to return to the cabin, I pushed off once more from the edge of the hatch to check on why there is angular velocity at the first moment after impact. I found that the slightest shift in direction of the force of the impact caused rotation in the corresponding plane. Those persons who will be working in space will obviously have much to do in securing their bodies while in weightlessness. As for the so-called psychological barrier that was supposed to be insurmountable by man preparing to confront the cosmic abyss alone, I not only did not sense any barrier, but even forgot that there could be one.

"I took the camera which filmed my stepping out into space and tried to enter the hatch immediately, but this was not too easy to do. After all, one is hampered when wearing a space suit. Considerable physical exertion was required, so that my taking leave of space was a rather protracted affair. At last I was in the air lock again and soon found myself in the cabin alongside Pavel Ivanovich who congratulated me on successfully carrying out the program for leaving the craft. Despite the rather strenuous physical exertion the independent life-support system was completely reliable, and I felt no lack of air or unfavorable temperature fluctuations. But when I was sitting in the chair, streams of sweat flowed down my forehead and cheeks. In my opinion, it is premature to compare space, as some journalists do, to a picnic ground."

/29

Several years ago the first pages of space physiology were written. Now there seems to be enough material to write the most important chapters. Our aim is to see to it that the designers, cosmonauts and scientists find in these materials useful and essential information to advance space science.

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